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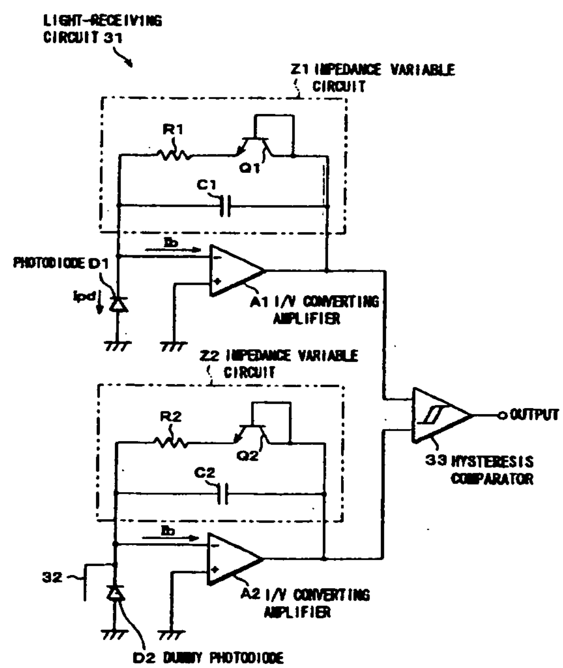
(54) Optical coupling device and light-receiving circuit of same

(57) In a light-receiving circuit 31 of an optical coupling device in which a dummy photodiode D2 is provided in a vicinity of a photodiode D1, and their outputs from current-to-voltage converting amplifiers A1 and A2 are compared with each other and subjected to waveform shaping by a hysteresis comparator 33 for improving a common mode rejection ratio, negative feedback circuits of the amplifiers A1 and A2 include impedance variable circuits Z1 and Z2 in which impedances decrease as a level of an inputted photoelectric current Ipd increases. Therefore, an increase of the current Ipd decreases gains of the amplifiers A1 and A2 and thus narrows a band, whereas a decrease of the current Ipd increases the gains and thus widens the band. This minimizes pulse width distortion caused by quantity changes of incoming light, thereby realizing a high-speed transmission rate.

FIG. 1



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Description

FIELD OF THE INVENTION

[0001] The present invention relates to an optical coupling device, which is realized as a photocoupler, for example, and a light-receiving circuit of the same, in particular to a high-speed light-receiving integrated circuit on a secondary side.

BACKGROUND OF THE INVENTION

[0002] Figure 6 is a cross-sectional view showing an arrangement of a typical photocoupler 1. The photocoupler 1 converts an electric signal, which is inputted from a terminal 2 on a primary side, into an optical signal by a light emitting integrated circuit 3 on the primary side, converts the optical signal back into an electric signal by a light-receiving integrated circuit 4 on a secondary side, and outputs the electric signal from a terminal 5 on the secondary side. This electrically isolates a circuit on the primary side from a circuit on the secondary side, thereby realizing sending and receiving of a signal while the devices are electrically insulated from each other. A light emitting element, such as a light emitting diode, on the light emitting integrated circuit 3 and a light-receiving element, such as a photodiode, on the light-receiving integrated circuit 4 are placed in a vicinity to face each other. A gap between the elements is filled with translucent epoxy resin 6 having a predetermined dielectric constant. Further, their outside is sealed with epoxy resin 7 having light blocking effect.

[0003] Figure 7 is a block diagram showing an electrical arrangement of a photocoupler 11 of a conventional art. The circuit on the primary side is composed of a sending driver IC 12 and a light emitting element 13, whereas the circuit on the secondary side is composed of a receiving IC 14. In the sending driver IC 12, an amplifier 15 converts a voltage signal, which is inputted to an input terminal IN, into a current signal, and a drive element 16 drives the light emitting element 13 to turn on by using the current signal, where a voltage between terminals Vcc 1 and GND 1 is a power supply voltage. Further, the circuit on the primary side may be composed of only a light emitting element for converting the inputted electronic signal into the optical signal.

[0004] In the receiving IC 14, a light-receiving element 17 converts the optical signal into a current signal, where a voltage between terminals Vcc 2 and GND 2 is a power supply voltage. The signal is then converted from current to voltage (hereinafter referred to as I/V conversion) by a current-to-voltage converting amplifier (hereinafter referred to as an I/V converting amplifier) 18, and is subjected to waveform shaping by a comparator 19, and outputted to an output terminal OUT.

[0005] Here, a pulse width distortion characteristic is an important characteristic for characterizing a photocoupler. Recently, FA (Factory Automation) devices especially have higher performance, for example, because a semiconductor has higher performance, digital devices are more widely used. This requires a photocoupler to have a high speed, which insulates between units of an AC servo or a programmable controller for the purpose of reducing noises, and protecting the devices. For example, a photocoupler with a transmission speed of 25 Mbps is required to have no more than ±6 nsec of the pulse width distortion when the pulse width is a 40 nsec.

[0006] On the other hand, due to unevenness in a quantity of light outputted by the light emitting element 13, manufacturing unevenness (unevenness caused during a manufacturing process) in distance between the sending-side circuit and the receiving-side circuit caused at a process of molding with the epoxy resins 6 and 7, and the like, a quantity of incoming light into the light-receiving element 17 is considerably changed. Furthermore, there is unevenness in a gain of the I/V converting amplifier 18 caused by manufacturing unevenness of the receiving-side circuit. For realizing a photocoupler having high-speed performance, it is necessary to minimize distortion of output pulse width, which is caused by quantity changes of incoming light into the light-receiving element 17.

[0007] Moreover, another important characteristic of characterizing a photocoupler is a common mode rejection ratio (CMRR). The CMR characteristics indicates how difficult it is to faultily operate by disturbance noise. As shown in Figure 6, the photocoupler 1 has a condenser structure, in which the epoxy resin 6 having a predetermined dielectric constant fills between the integrated circuits 3 and 4, so that the integrated circuits 3 and 4 are connected by a parasitic capacitor thereof. Accordingly, when the input side and the output side of the photocoupler 1 receive steep noise in which a rising and a falling of the pulse are (dv/dt), a noise current of C·(dv/dt) flows between the input side and the output side, where the parasitic capacitor is C. Then the noise current causes the faulty operation, when a part of the noise current flows into the light-receiving element on the light-receiving integrated circuit 4.

[0008] One of methods to prevent the faulty operation is a method in which the light-receiving element is covered with a transparent conductive film such as an ITO film, and its potential is grounded to a GND potential on the receiving side. In such an arrangement, the noise current caused by the parasitic capacitor flows into a GND on the output side via the transparent conductive film, and the light-receiving element receives only the optical signal of the input side. This prevents the faulty operation due to noise, and thus realizing high CMR characteristics. However, this causes a

problem that the process becomes complicated because it requires a specialized processing device for forming the conductive film.

[0009] Therefore, another method to prevent the faulty operation caused by the parasitic capacitor is an arrangement to employ a dummy photodiode, as disclosed in Japanese Patent No. 2531070 (publication date: September 4, 1996), for example. Figure 8 is a block diagram showing a light-receiving circuit 21 of another conventional art using such a dummy photodiode. The light-receiving circuit 21 is provided with two photodiodes d1 and d2 having identical properties in an identical shape and quantity. Only the photodiode d1 is used for receiving the optical signal from the light emitting element, whereas the other photodiode d2 is shielded from light to be used as a dummy photodiode. The dummy photodiode d2, having its light-receiving face covered with a cathode metal wiring 22, is shielded from light with a cathode potential.

[0010] The photodiode d1 and the photodiode d2 are positioned in a cross manner having a checker-board like arrangement, as shown in Figure 9. In addition, the photodiodes d1 and d2 have an area of approximately 0.1×0.1 mm, which is sufficiently small, whereas frames on which the integrated circuits 3 and 4 are mounted have a size of, for example, 2×2mm. This makes the noise currents flown into the photodiodes d1 and d2 substantially identical.

[0011] Therefore, output currents from the photodiodes d1 and d2 are subjected to the I/V conversion respectively by the I/V converting amplifiers a1 and a2, and compared with each other by a hysteresis comparator 23, which is a differential amplifier, and thus the output from the photodiode dl is subjected to waveform shaping into a pulse signal. This eliminates a common mode noise component, thereby realizing the output of high CMR characteristics.

[0012] However, the I/V converting amplifiers a1 and a2 are amplifiers for linear amplification subjected to negative feedback by resistors r1 and r2 as well as condensers c1 and c2. Therefore, for minimizing the distortion of the output pulse width caused by the quantity changes of incoming light, a first stage of the amplifier needs to have a sufficiently wide band. However, there is a problem that the CMR characteristics are deteriorated, when the band of the amplifier is wide.

[0013] Namely, the photocoupler of high speed and high CMR having the transmission speed of 25 Mbps has an objective to achieve that CMR tolerance is 10 kV/μsec and Vcm = 1000V (here, the wording "CMR tolerance" means a level of CMR up to which the photocoupler can tolerate the noise in the common mode noise signal). In this case, as shown in Figure 10(a), where a rise time of a noise pulse is 100 nsec, its pulse height value is 1kV. As a result, a noise current waveform flown to the photodiodes d1 and d2 by coupling primary and secondary capacitors has a pulse waveform of 100 nsec, as shown in Figure 10(b). Therefore, since the noise current waveform includes a high-frequency component of 10 MHz or more, when the band of the amplifier is widened more than a band corresponding to the 25 Mbps, the high-frequency component is easily amplified, and thus easily causing the faulty operation due to noise.

[0014] For this reason, the amplifier band cannot be used for obtaining the CMR characteristics, so the quantity of incoming light into the photodiode d1 is required to be constant for obtaining the CMR characteristics. This narrows an allowance for the manufacturing unevenness, thereby causing a problem that a photocoupler of high speed and high CMR is difficult to be manufactured with a sufficient yield.

SUMMARY OF THE INVENTION

[0015] The object of the present invention is to provide an optical coupling device having a high-speed transmission rate of a pulse, wherein the optical coupling device minimizes pulse width distortion caused by quantity changes of incoming light directed into a light-receiving element, without being made susceptible to faulty operation due to noise.

[0016] In order to achieve the object, an optical coupling device of the present invention is so adapted that a circuit on a primary side uses a light emitting element to convert an inputted electric signal into an optical signal, whereas a circuit on a secondary side, in which a light-receiving element is placed in a vicinity of the light emitting element so as to face the light emitting element, uses the light-receiving element to accept the optical signal and to convert the optical signal into an electric signal, then outputs the electric signal, wherein the circuit on the secondary side includes impedance variable means in a negative feedback circuit of a current-to-voltage converting amplifier (an I/V converting amplifier) for amplifying the photoelectric current produced from the photo-electric conversion by the light-receiving element, the impedance variable section changing an impedance in accordance with a level of the inputted photoelectric current, wherein the impedance variable section lowers a gain of the I/V converting amplifier as the level of the inputted photoelectric current increases.

[0017] According to the arrangement, the optical coupling device realized as, for example, a photocoupler, which electrically isolates the circuit on the primary side from the circuit on the secondary side by converting the inputted electric signal into the optical signal by the circuit on the primary side and converting it back into the electric signal by the circuit on the secondary side, including the impedance variable section in the negative feedback circuit of the current-to-voltage converting amplifier for amplifying the photoelectric current produced from the photo-electric conversion by the light-receiving element, the impedance variable section changing an impedance in accordance with a level of the inputted photoelectric current, wherein the impedance variable section raises the gain of the I/V converting

amplifier as the level of the inputted photoelectric current decreases and lowers the gain when the level of the inputted photoelectric current increases. Because of this, even when the outputs from the I/V converting amplifier are subjected to waveform shaping at the same threshold value, it is possible to minimize pulse width distortion caused by the light quantity. This realizes the high-speed transmission rate of the pulse.

[0018] Moreover, in an arrangement including two sets of the circuits on the secondary side in which the light-receiving elements are used as a photodiode and a dummy photodiode for the purpose of eliminating a common mode noise signal, both gains of the I/V converting amplifiers decrease with respect to the common mode current due to the noise, thereby restricting the faulty operation, and thus increasing the CMR characteristics.

[0019] For a fuller understanding of the nature and advantages of the invention, reference should be made to the ensuing detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020]

Figure 1 is a block diagram showing an electrical arrangement of a light-receiving circuit of an embodiment of the present invention.

Figure 2 is a block diagram showing an electrical arrangement of a light-receiving circuit of another embodiment of the present invention.

Figures 3(a) and 3(b) are graphs showing frequency characteristics of I/V converting amplifiers in the light-receiving circuits of Figures 1 and 2.

Figure 4 is a block diagram showing an electrical arrangement of a light-receiving circuit of still another embodiment of the present invention.

Figure 5 is a front view showing a configuration of a photodiode and a dummy photodiode in the light-receiving circuit of Figure 4.

Figure 6 is a cross-sectional view showing a structure of a typical photocoupler.

Figure 7 is a block diagram showing an electrical arrangement of a photocoupler of a typical art.

Figure 8 is a block diagram showing an electrical arrangement of a light-receiving circuit of another conventional art.

Figure 9 is a front view showing a configuration of a photodiode and a dummy photodiode in the light-receiving circuit of Figure 8.

Figures 10(a) and 10(b) are diagrams showing noise applied to the photocoupler and an output waveform of the photodiode caused by the noise.

DESCRIPTION OF THE EMBODIMENTS

[0021] An embodiment of the present invention is described as follows, referring to Figures 1 through 5.

[0022] Figure 1 is a block diagram showing an electrical arrangement of a light-receiving circuit 31 of the embodiment of the present invention. The light-receiving circuit 31 is provided with two photodiodes D1 and D2 having identical properties in an identical shape and quantity. Only the photodiode D1 is used for receiving the optical signal from the light emitting element, whereas the other photodiode, that is, the photodiode D2 is a dummy photodiode by being shielded from light. The dummy photodiode D2, having its light-receiving face covered with a cathode metal wiring 32, is shielded from light where a cathode potential is applied on the cathode metal wiring 32.

[0023] Output currents from the photodiodes D1 and D2 are converted into voltage respectively by the I/V converting amplifiers A1 and A2, and compared from each other by a hysteresis comparator 33, which is a differential amplifier. In this way, the output from the photodiode D1 is subjected to waveform shaping to be a pulse signal. This eliminates a common mode noise component, thereby realizing the output of high CMR characteristics.

[0024] Notably, in the present invention, the I/V converting amplifiers A1 and A2 are amplifiers of nonlinear amplification that carry out negative feedback respectively via impedance variable circuits Z1 and Z2. The impedance variable circuit Z1 is composed of (a) a series circuit of a resistor R1 and a transistor Q1 arranged to have a diode structure (later described), and (b) a condenser C1, the series circuit and the condenser being provided in parallel between an output and a negative input of the I/V converting amplifier A1. Further, for achieving consistency, also on the dummy photodiode D2 side, the impedance variable circuit Z2 is composed of (a) a series circuit of a resistor R2 and a transistor Q2 arranged to have a diode structure (later described), and (b) a condenser C2, the series circuit and the condenser being provided in parallel between an output and a negative input of the I/V converting amplifier A2. Note that, here, the above arrangement satisfies R2 = R1, Q2 = Q1, and C2 = C1.

[0025] Therefore, when a current flowing through the photodiode D1 is Ipd, and a bias current of an input terminal of the I/V converting amplifier A1 is Ib, an impedance Z1 of the impedance variable circuit Z1 is expressed as follows:

$$Z1 = R1 + (kT/q) / (Ib+Ipd), \quad (1)$$

where k is the Boltzmann constant, T is the absolute temperature, and q is an elementary electric charge.

[0026] Accordingly, since an increase of the current Ipd of the photodiode D1 decreases the impedance Z1, an input of a big signal lowers a gain of the I/V converting amplifier A1. Thus, since the I/V converting amplifier A1 gives the hysteresis comparator 33 an output voltage subjected to logarithmic compression, it is possible to prevent an output pulse width from being increased, even when the hysteresis comparator 33 carries out waveform shaping at a fixed threshold value from the I/V converting amplifier A2. Further, when a common mode current due to noise flows through the dummy photodiode D2 and the photodiode D1, gains of the I/V converting amplifiers A1 and A2 are lowered. This restricts the faulty operation, and thus realizing high CMR characteristics.

[0027] Moreover, when the band of the I/V converting amplifier A1 itself is wide enough, a cutoff frequency (band) fc of the I/V converting amplifier A1 is expressed as follows:

$$fc = 1 / (2\pi \cdot C1 \cdot Z1). \quad (2)$$

[0028] Accordingly, when the current Ipd of the photodiode D1 increases and the impedance Z1 decreases as described above, the cutoff frequency fc increases. For example, where R1 = 5kΩ, C1 = 0.3pF, Ib = 2μA, Ipd = 1μA, and T = 300K, Z1 = 13.6kΩ and fc = 39MHz are given. Here, if the current Ipd increases to 2μA, Z1 = 11.45kΩ and fc = 46.3MHz are given.

[0029] As described above, according to the equation 2, the band of the I/V converting amplifier A1 is widen when according to the equation 1 the impedance Z1 is lowered, in proportion to the current Ipd of the photodiode D1, by inserting the condenser C1 in parallel to the series circuit of the transistor Q1 and the resistor R1 that vary the impedance Z1. This further reduces pulse width distortion caused by quantity changes of incoming light. Further, this narrows the band of the I/V converting amplifier A1 when the current Ipd of the photodiode D1 does not flow, thereby helping realization of high CMR characteristics.

[0030] Another embodiment of the present invention is explained as follows, referring to Figures 2, 3(a), and 3(b).

[0031] Figure 2 is a block diagram showing an electrical arrangement of a light-receiving circuit 41 of the another embodiment of the present invention. Since the light-receiving circuit 41 is similar to the above-described light-receiving circuit 31, the same reference codes are assigned to the corresponding sections, and explanation thereof is omitted here.

[0032] In the light-receiving circuit 31, the transistors Q1 and Q2, which varies impedances in the impedance variable circuits Z1 and Z2, have diode structures in which a collector and a base are connected. Meanwhile, in impedance variable circuits Z1a and Z2a in the light-receiving circuit 41, resistors R1a and R2a are respectively provided between the collector and the base, and I/V converting amplifiers A1 and A2 have frequency characteristics having a peak. In addition, a dummy photodiode D2 side is arranged to satisfy R2a = R1a, as well as R2 = R1 that is described above, for achieving consistency.

[0033] Therefore, the equation 1 is expressed as follows:

$$Z1 = R1 + R1a / hFE(Q1) + (kT/q) / (Ib+Ipd), \quad (3)$$

where hFE(Q1) is a current amplification ratio of the transistor Q1. The current amplification ratio hFE, having frequency characteristics, is expressed in complex variables as follows;

$$hFE(jf) = hFE0 / (1+hFE0 \cdot (f/fTh) \cdot j), \quad (4)$$

where fTh is called as a transient frequency, which is a frequency to satisfy hFE = 1.

[0034] On the other hand, an impedance of a gain resistance, which is a value that is obtained when Z1 and C1 are connected in parallel, has frequency characteristics.

$$\text{Gain resistance} = Z1//C1 = Z1 / (1+2\pi \cdot f \cdot C1 \cdot j) \quad (5)$$

[0035] Though this calculation is very complicated, when R1 = 5kΩ, R1a = 10kΩ, C1 = 0.3pF, Ib = 2μA, Ipd = 5μA, T = 300K, hFE0 = 100, and fTh = 1GHz, for example, the calculation of the frequency characteristics of the gain

resistance according to the equation 5 gives a result as shown in Figure 3(a), and thus causing peaking. The peak is eliminated when the resistor R1a is reduced.

[0036] The frequency characteristics of the I/V converting amplifier A1 using the impedance variable circuit Z1 is indicated by the reference code $\alpha 1$ in Figure 3(b). Accordingly, an increase of the frequency decreases hFE (Q1) and increases the impedance Z1 when the impedance variable circuit Z1a is used. For this reason, in the frequency characteristics, according to the equation 2, peaking of the gain occur around the cutoff frequency fc, as indicated by the reference code $\alpha 2$. This increases the extension rate of a band with respect to the current Ipd of the photodiode D1, thereby further reducing the pulse width distortion due to unevenness of the current Ipd.

[0037] Still another embodiment of the present invention is described as follows, referring to Figures 4, 5, and 9.

[0038] Figure 4 is a block diagram showing an electrical arrangement of a light-receiving circuit 51 of the still another embodiment of the present invention. Since the light-receiving circuit 51 is similar to the above-mentioned light-receiving circuits 31 and 41, the same reference codes are assigned to the corresponding sections, and thus explanation thereof is omitted here. Notably, in the light-receiving circuit 51, an output terminal of the I/V converting amplifier A1 on the photodiode D1a side is provided with an offset circuit 52 for adjusting its sensitivity in signal reception. Therefore, because as described above, consistency is achieved between the I/V converting amplifiers A1 and A2 or the impedance variable circuits Z1 and Z2 (Z1a and Z2a), which are respectively provided in the photodiode D1a side and the dummy photodiode D2 side, a little inconsistency is caused in the output terminals thereof, here.

[0039] For this reason, the photodiode D1a and the dummy photodiode D2 are formed to have different areas respectively as shown in Figure 5 so as to cancel the inconsistency, whereas normally they are formed to have an equal area as shown in Figure 9. The area ratio is about 1 : 0.9. In this way, the light-receiving circuit 51 is composed for obtaining the best CMR characteristics.

[0040] As described above, the optical coupling device of the present invention realized as, for example, a photocoupler, is so adapted that impedance variable means in a negative feedback circuit of an I/V converting amplifier for amplifying the photoelectric current produced from the photo-electric conversion by the light-receiving element, the impedance variable means changing an impedance in accordance with a level of the inputted photoelectric current, wherein the impedance variable means raises a gain of the I/V converting amplifier as the level of the inputted photoelectric current decreases and lowers the gain when the level of the inputted photoelectric current increases.

[0041] Because of this, even when the outputs from the I/V converting amplifier are subjected to waveform shaping at the same threshold value, it is possible to minimize pulse width distortion caused by the light quantity. This realizes the high-speed transmission rate of the pulse. Moreover, in an arrangement including two sets of the circuits on the secondary side in which the light-receiving elements are used as a photodiode and a dummy photodiode for the purpose of eliminating a common mode noise signal, both gains of the I/V converting amplifiers decrease with respect to the common mode current due to the noise, thereby restricting the faulty operation, and thus increasing the CMR characteristics.

[0042] Moreover, an optical coupling device of the present invention is so adapted that a circuit on a primary side includes a light emitting element for converting an inputted electric signal into an optical signal, and a circuit on a secondary side includes (a) a light-receiving element, which is placed in a vicinity of the light emitting element so as to face the light emitting element, the light-receiving element receiving the optical signal and performing photo-electric conversion of the optical signal, and (b) an I/V converting amplifier for amplifying the photoelectric current subjected to the photo-electric conversion by the light-receiving element and outputting the photoelectric current, wherein the I/V converting amplifier includes a negative feedback circuit having impedance variable means for lowering a gain of the I/V converting amplifier as a level of the inputted photoelectric current increases.

[0043] According to the arrangement, even when the outputs from the I/V converting amplifier are subjected to waveform shaping at the same threshold value, it is possible to minimize pulse width distortion caused by the light quantity. This realizes the high-speed transmission rate of the pulse. Moreover, in an arrangement including two sets of the circuits on the secondary side in which the light-receiving elements are used as a photodiode and a dummy photodiode for the purpose of eliminating a common mode noise signal, both gains of the I/V converting amplifiers decrease with respect to the common mode current due to the noise, thereby restricting the faulty operation, and thus increasing the CMR characteristics.

[0044] Moreover, it is more preferable that the impedance variable means is composed of (a) a series circuit of a first resistor and a transistor, and (b) a condenser, the series circuit and the condenser being provided in parallel between an output and a negative input of the I/V converting amplifier.

[0045] With this arrangement where the condenser is inserted in parallel to the series circuit of the transistor and the first resistor that varies the impedance, the band of the I/V converting amplifier is widen when the impedance is lowered, in proportion to the current flowing through the light-receiving element. This further reduces pulse width distortion caused by quantity changes of incoming light. Further, this narrows the band of the I/V converting amplifier when the current of the light-receiving element does not flow, thereby helping realization of high CMR characteristics.

[0046] Moreover, it is more preferable that the impedance variable means is composed of (a) a series circuit of a

first resistor and a transistor, (b) a condenser, and (c) a second resistor, the series circuit and the condenser being provided in parallel between an output and a negative input of the I/V converting amplifier, and the second resistor being provided between a collector and a base of the transistor.

[0047] According to this, when the frequency of the inputted photoelectric current increases, the current amplification ratio of the transistor in the impedance variable means decreases and the impedance of the impedance variable means increases. For this reason, in the frequency characteristics of the I/V converting amplifier, peaking of the gain occurs around the cutoff frequency. This increases the extension rate of a band with respect to the photoelectric current, thereby further reducing the pulse width distortion caused by unevenness of the photoelectric current.

[0048] Moreover, it is more preferable that the light-receiving element is composed of a photodiode and a dummy photodiode, respectively having an I/V converting amplifier so as to eliminate a common mode noise signal, the optical coupling device including an offset circuit at an output terminal of the I/V converting amplifier on the photodiode side for adjusting sensitivity in signal reception, wherein the photodiode and the dummy photodiode are formed to have different areas respectively so as to cancel inconsistency in outputs of the I/V converting amplifiers caused by the offset circuit.

[0049] According to this, the common mode noise signal is eliminated by providing the dummy photodiode to the photodiode and obtaining a difference between outputs of the I/V converting amplifiers respectively corresponding to the photodiode and the dummy photodiode. Moreover, in an arrangement for achieving high CMR characteristics, an area ratio between the photodiode and the dummy photodiode are adjusted so that it is possible to cancel the inconsistency in outputs caused by the offset circuit provided for adjusting the sensitivity in signal reception. Accordingly, the sensitivity in signal reception can be easily adjusted.

[0050] In order to solve the problems, an optical coupling device of the present invention is so adapted that a circuit on a primary side includes a light emitting element for converting an inputted electric signal into an optical signal and a circuit on a secondary side includes (a) a light-receiving element, which is placed in a vicinity of the light emitting element so as to face the light emitting element, the light-receiving element receiving the optical signal, and (b) an I/V converting amplifier for amplifying the photoelectric current subjected to the photo-electric conversion by the light-receiving element, wherein the circuit on the secondary side includes a photodiode and a dummy photodiode as light-receiving elements, and I/V converting amplifiers respectively corresponding to the photodiode and the dummy photodiode, and wherein the I/V converting amplifier includes a negative feedback circuit having impedance variable means for lowering a gain of the I/V converting amplifier as a level of the inputted photoelectric current increases.

[0051] According to the arrangement, even when the outputs from the I/V converting amplifier are subjected to waveform shaping at the same threshold value, it is possible to minimize pulse width distortion caused by the light quantity. This realizes the high-speed transmission rate of the pulse. Moreover, in an arrangement including two sets of the circuits on the secondary side in which the light-receiving elements are used as a photodiode and a dummy photodiode for the purpose of eliminating a common mode noise signal, both gains of the I/V converting amplifiers decrease with respect to the common mode current due to the noise, thereby restricting the faulty operation, and thus increasing the CMR characteristics.

[0052] Moreover, it is more preferable that the impedance variable means is composed of (a) a series circuit of a first resistor and a transistor, and (b) a condenser, the series circuit and the condenser being provided in parallel between an output and a negative input of the I/V converting amplifier.

[0053] With this arrangement where the condenser is inserted in parallel to the series circuit of the transistor and the first resistor that varies the impedance, the band of the I/V converting amplifier is widen when the impedance is lowered, in proportion to the current flowing through the light-receiving element. This further reduces pulse width distortion caused by quantity changes of incoming light. Further, this narrows the band of the I/V converting amplifier when the current of the light-receiving element does not flow, thereby helping realization of high CMR characteristics.

[0054] Moreover, it is preferable that the impedance variable means includes a second resistor provided between a collector and a base of the transistor.

[0055] This increases the extension rate of the band with respect to the current of the light-receiving element, thereby further reducing the pulse width distortion caused by unevenness of the current.

[0056] Moreover, it is preferable that an offset circuit is provided at an output terminal of the I/V converting amplifier on the photodiode side of the I/V converting amplifiers respectively corresponding to the photodiode and the dummy photodiode, the offset circuit adjusting sensitivity in signal reception, wherein the photodiode and the dummy photodiode are formed so as to have different areas respectively.

[0057] According to this, the common mode noise signal is eliminated by providing the dummy photodiode to the photodiode and obtaining a difference between outputs of the I/V converting amplifiers respectively corresponding to them. Moreover, in the arrangement for achieving high CMR characteristics, an area ratio between the photodiode and the dummy photodiode are adjusted so that it is possible to cancel the inconsistency in outputs caused by the offset circuit provided for adjusting the sensitivity in signal reception. Accordingly, the sensitivity in signal reception can be easily adjusted.

[0058] Moreover, in order to solve the problems, a light-receiving circuit of an optical coupling device of the present invention includes a light-receiving element, which is placed in a vicinity of the light emitting element so as to face the light emitting element for converting an inputted electric signal into an optical signal, the light-receiving element receiving the optical signal and performing photo-electric conversion of the optical signal, an I/V converting amplifier for amplifying the photoelectric current subjected to the photo-electric conversion by the light-receiving element and outputting the photoelectric current, wherein the I/V converting amplifier includes a negative feedback circuit having impedance variable means for lowering a gain of the I/V converting amplifier as a level of the inputted photoelectric current increases.

[0059] According to the arrangement, even when the outputs from the I/V converting amplifier are subjected to waveform shaping at the same threshold value, it is possible to minimize pulse width distortion caused by the light quantity. This realizes the high-speed transmission rate of the pulse. Moreover, in the arrangement including two sets of the circuits on the secondary side in which the light-receiving elements are used as a photodiode and a dummy photodiode for the purpose of eliminating a common mode noise signal, both gains of the I/V converting amplifiers decrease with respect to the common mode current due to the noise, thereby restricting the faulty operation, and thus increasing the CMR characteristics.

[0060] Moreover, in order to solve the problems, a light-receiving circuit of an optical coupling device of the present invention includes a light-receiving element, which is placed in a vicinity of a light emitting element so as to face the light emitting element for converting an inputted electric signal into an optical signal, the light-receiving element receiving the optical signal, an I/V converting amplifier for amplifying the photoelectric current subjected to the photo-electric conversion by the light-receiving element, wherein the photodiode and the dummy photodiode compose the light-receiving elements, and the I/V converting amplifier respectively corresponds to the photodiode and the dummy photodiode, and wherein the I/V converting amplifier includes a negative feedback circuit having impedance variable means for lowering a gain of the I/V converting amplifier as a level of the inputted photoelectric current increases.

[0061] According to the arrangement, even when the outputs from the I/V converting amplifier are subjected to the waveform shaping at the same threshold value, it is possible to minimize pulse width distortion caused by the light quantity. This realizes the high-speed transmission rate of the pulse. Moreover, in the arrangement including two sets of the circuits on the secondary side in which the light-receiving elements are used as a photodiode and a dummy photodiode for the purpose of eliminating a common mode noise signal, both gains of the I/V converting amplifiers decrease with respect to the common mode current due to the noise, thereby restricting the faulty operation, and thus increasing the CMR characteristics.

[0062] Moreover, it is preferable that the impedance variable means is composed of (a) a series circuit of a first resistor and a transistor, and (b) a condenser, the series circuit and the condenser being provided in parallel between an output and a negative input of the I/V converting amplifier.

[0063] With this arrangement where the condenser is inserted in parallel to the series circuit of the transistor and the first resistor that varies the impedance, the band of the I/V converting amplifier is widen when the impedance is lowered, in proportion to the current flowing through the light-receiving element. This further reduces pulse width distortion caused by quantity changes of incoming light. Further, this narrows the band of the I/V converting amplifier when the current of the light-receiving element does not flow, thereby helping realization of high CMR characteristics.

[0064] Moreover, it is preferable that the impedance variable means includes a second resistor, which is provided between a collector and a base of the transistor.

[0065] This increases the extension rate of the band with respect to the current of the light-receiving element, thereby further reducing the pulse width distortion caused by unevenness of the current.

[0066] Moreover, it is preferable that an offset circuit at an output terminal of the I/V converting amplifier on the photodiode side of the I/V converting amplifiers respectively corresponding to the photodiode and the dummy photodiode, the offset circuit adjusting sensitivity in signal reception, wherein the photodiode and the dummy photodiode are formed so as to have different areas respectively.

[0067] According to this, the common mode noise signal is eliminated by providing the dummy photodiode to the photodiode and obtaining a difference between outputs of the I/V converting amplifiers respectively corresponding to them. Moreover, in the arrangement for achieving high CMR characteristics, an area ratio between the photodiode and the dummy photodiode are adjusted so that it is possible to cancel the inconsistency in outputs caused by the offset circuit provided for adjusting the sensitivity in signal reception. Accordingly, the sensitivity in signal reception can be easily adjusted.

[0068] The invention being thus described, it will be obvious that the same way may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

Claims

1. An optical coupling device, in which a circuit on a primary side uses a light emitting element to convert an inputted electric signal into an optical signal, whereas a circuit on a secondary side (31), in which a light-receiving element (D1) is placed in a vicinity of the light emitting element so as to face the light emitting element, uses the light-receiving element (D1) to accept the optical signal and to convert the optical signal into an electric signal, then outputs the electric signal, wherein:

   the circuit on the secondary side (31) includes impedance variable means (Z1) in a negative feedback circuit of a current-to-voltage converting amplifier (an I/V converting amplifier; A1) for amplifying the photoelectric current produced from the photo-electric conversion by the light-receiving element (D1), the impedance variable means (Z1) changing an impedance in accordance with a level of the inputted photoelectric current, wherein the impedance variable means (Z1) lowers a gain of the I/V converting amplifier (A1) as the level of the inputted photoelectric current increases.

2. An optical coupling device, wherein:

   a circuit on a primary side includes a light emitting element for converting an inputted electric signal into an optical signal; and
   a circuit on a secondary side (31) includes (a) a light-receiving element (D1), which is placed in a vicinity of the light emitting element so as to face the light emitting element, the light-receiving element (D1) receiving the optical signal and performing photo-electric conversion of the optical signal, and (b) an I/V converting amplifier (A1) for amplifying the photoelectric current subjected to the photo-electric conversion by the light-receiving element (D1) and outputting the photoelectric current,

   wherein the I/V converting amplifier (A1) includes a negative feedback circuit having impedance variable means (Z1) for lowering a gain of the I/V converting amplifier (A1) as a level of the inputted photoelectric current increases.

3. The optical coupling device as set forth in claim 1 or 2, wherein:

   the impedance variable means (Z1) is composed of (a) a series circuit of a first resistor (R1) and a transistor (Q1), and (b) a condenser (C1), the series circuit and the condenser (C1) being provided in parallel between an output and a negative input of the I/V converting amplifier (A1).

4. The optical coupling device as set forth in claim 1 or 2, wherein:

   the impedance variable means (Z1) is composed of (a) a series circuit of a first resistor (R1) and a transistor (Q1), (b) a condenser (C1), and (c) a second resistor (R1a), the series circuit and the condenser (C1) being provided in parallel between an output and a negative input of the I/V converting amplifier (A1), and the second resistor being provided between a collector and a base of the transistor (Q1).

5. The optical coupling device as set forth in any one of claims 1 through 4, wherein the light-receiving element (D1) is composed of a photodiode (D1) and a dummy photodiode (D2), respectively having an I/V converting amplifier (A1) so as to eliminate a common mode noise signal, the optical coupling device comprising:

   an offset circuit (52) at an output terminal of the I/V converting amplifier (A1) on the photodiode (D1) side for adjusting sensitivity in signal reception,

   wherein the photodiode (D1) and the dummy photodiode (D2) are formed to have different areas respectively so as to cancel inconsistency in outputs of the I/V converting amplifiers (A1) caused by the offset circuit (52).

6. An optical coupling device, wherein:

   a circuit on a primary side includes a light emitting element for converting an inputted electric signal into an optical signal; and
   a circuit on a secondary side (31) includes (a) a light-receiving element (D1), which is placed in a vicinity of the light emitting element so as to face the light emitting element, the light-receiving element (D1) receiving

the optical signal, and (b) an I/V converting amplifier (A1) for amplifying the photoelectric current subjected to the photo-electric conversion by the light-receiving element (D1),

wherein the circuit on the secondary side (31) includes a photodiode (D1) and a dummy photodiode (D2) as light-receiving elements (D1), and I/V converting amplifiers (A1, A2) respectively corresponding to the photodiode (D1) and the dummy photodiode (D2), and

wherein the I/V converting amplifier (A1, A2) includes a negative feedback circuit having impedance variable means (Z1, Z2) for lowering a gain of the I/V converting amplifier (A1, A2) as a level of the inputted photoelectric current increases.

7. The optical coupling device as set forth in claim 6, wherein:

the impedance variable means (Z1, Z2) is composed of (a) a series circuit of a first resistor (R1, R2) and a transistor (Q1, Q2), and (b) a condenser (C1, C2), the series circuit and the condenser (C1, C2) being provided in parallel between an output and a negative input of the I/V converting amplifier (A1, A2).

8. The optical coupling device as set forth in claim 7, wherein:

the impedance variable means (Z1, Z2) includes a second resistor (R1a, R2a), which is provided between a collector and a base of the transistor (Q1, Q2).

9. The optical coupling device as set forth in any one of claims 6 through 8, comprising:

an offset circuit (52) at an output terminal of the I/V converting amplifier (A1) on the photodiode (D1) side of the I/V converting amplifiers (A1, A2) respectively corresponding to the photodiode (D1) and the dummy photodiode (D2), the offset circuit (52) adjusting sensitivity in signal reception,

wherein the photodiode (D1) and the dummy photodiode (D2) are formed so as to have different areas respectively.

10. A light-receiving circuit (31) of an optical coupling device, comprising:

a light-receiving element (D1), which is placed in a vicinity of the light emitting element so as to face the light emitting element for converting an inputted electric signal into an optical signal, the light-receiving element (D1) receiving the optical signal and performing photo-electric conversion of the optical signal;
an I/V converting amplifier (A1) for amplifying the photoelectric current subjected to the photo-electric conversion by the light-receiving element (D1) and outputting the photoelectric current,

wherein the I/V converting amplifier (A1) includes a negative feedback circuit having impedance variable means (Z1) for lowering a gain of the I/V converting amplifier (A1) as a level of the inputted photoelectric current increases.

11. A light-receiving circuit (31) of an optical coupling device, comprising:

a light-receiving element (D1), which is placed in a vicinity of a light emitting element so as to face the light emitting element for converting an inputted electric signal into an optical signal, the light-receiving element (D1) receiving the optical signal;
an I/V converting amplifier (A1) for amplifying the photoelectric current subjected to the photo-electric conversion by the light-receiving element (D1),

wherein the photodiode (D1) and the dummy photodiode (D2) compose the light-receiving elements (D1), and the I/V converting amplifier (A1, A2) respectively corresponds to the photodiode (D1) and the dummy photodiode (D2),

wherein the I/V converting amplifier (A1, A2) includes a negative feedback circuit having impedance variable means (Z1, Z2) for lowering a gain of the I/V converting amplifier (A1, A2) as a level of the inputted photoelectric current increases.

12. The light-receiving circuit (31) of the optical coupling device as set forth in claim 10 or 11,

wherein:

the impedance variable means (Z1, Z2) is composed of (a) a series circuit of a first resistor (R1, R2) and a transistor (Q1, Q2), and (b) a condenser (C1, C2), the series circuit and the condenser (C1, C2) being provided in parallel between an output and a negative input of the I/V converting amplifier (A1, A2).

13. The light-receiving circuit (31) of the optical coupling device as set forth in claim 12, wherein:

the impedance variable means (Z1, Z2) includes a second resistor (R1a, R2a), which is provided between a collector and a base of the transistor (Q1, Q2).

14. The light-receiving circuit (31) of the optical coupling device as set forth in claim 11, comprising:

an offset circuit (52) at an output terminal of the I/V converting amplifier (A1) on the photodiode side of the I/V converting amplifiers (A1, A2) respectively corresponding to the photodiode (D1) and the dummy photodiode (D2), the offset circuit (52) adjusting sensitivity in signal reception,

wherein the photodiode (D1) and the dummy photodiode (D2) are formed so as to have different areas respectively.

FIG. 1

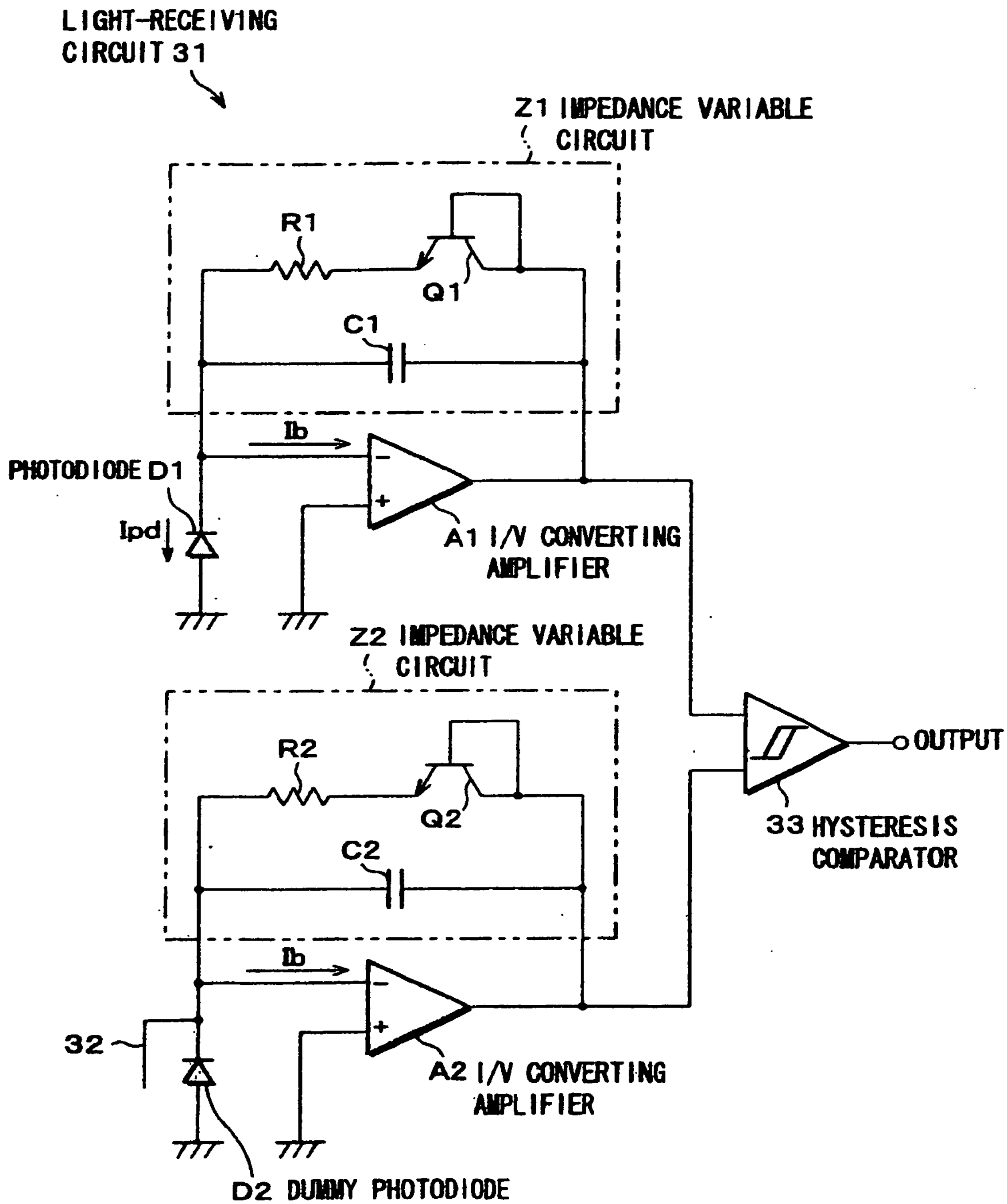

LIGHT-RECEIVING CIRCUIT 31
Z1 IMPEDANCE VARIABLE CIRCUIT
R1
Q1
C1
Ib
PHOTODIODE D1
Ipd
A1 I/V CONVERTING AMPLIFIER
Z2 IMPEDANCE VARIABLE CIRCUIT
R2
Q2
C2
Ib
32
A2 I/V CONVERTING AMPLIFIER
D2 DUMMY PHOTODIODE
OUTPUT
33 HYSTERESIS COMPARATOR

FIG. 2

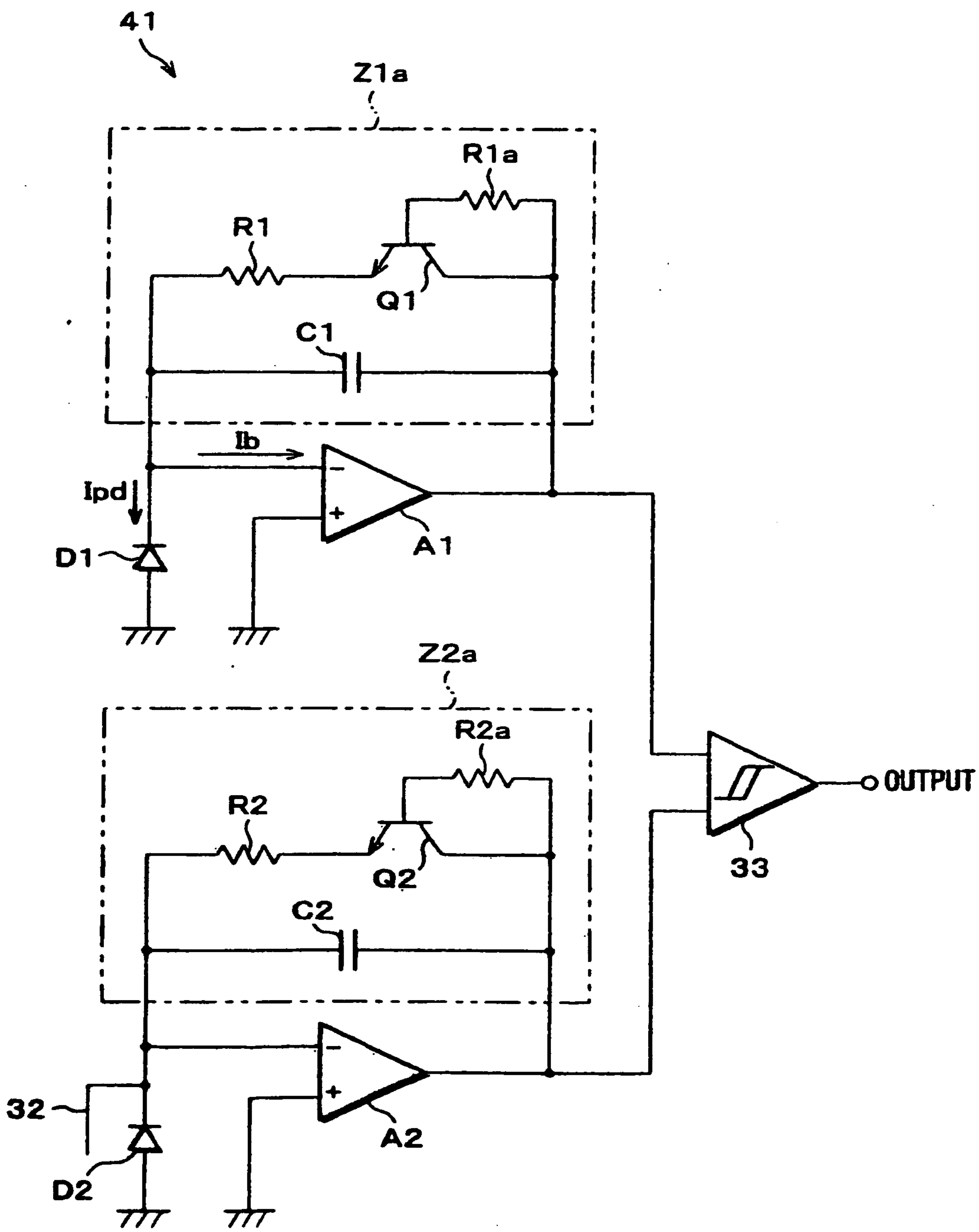


FIG. 3 (a)

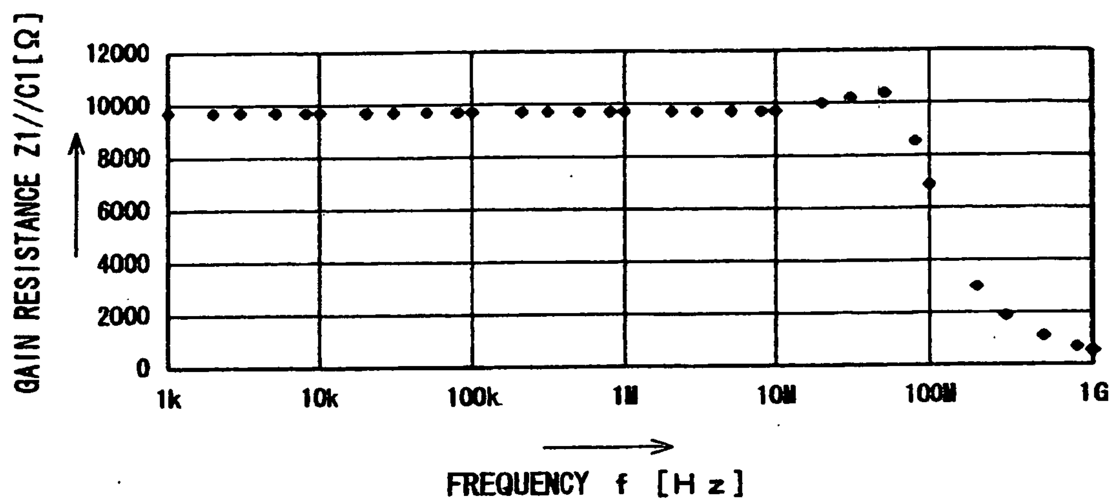

GAIN RESISTANCE Z1//C1[Ω]
12000
10000
8000
6000
4000
2000
0
1k
10k
100k
1M
10M
100M
1G
FREQUENCY f [H z]

FIG. 3 (b)

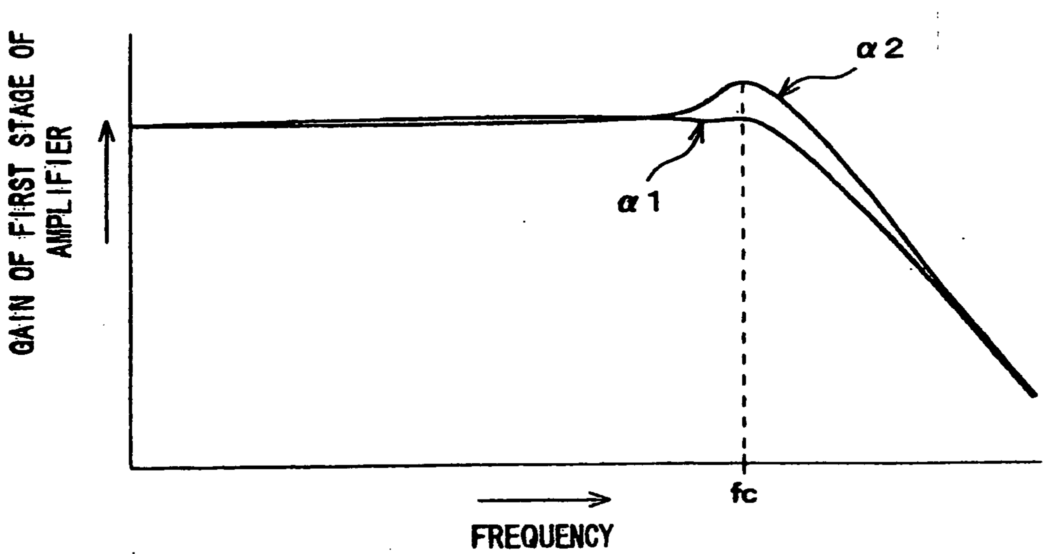

GAIN OF FIRST STAGE OF AMPLIFIER
α2
α1
fc
FREQUENCY

FIG. 4

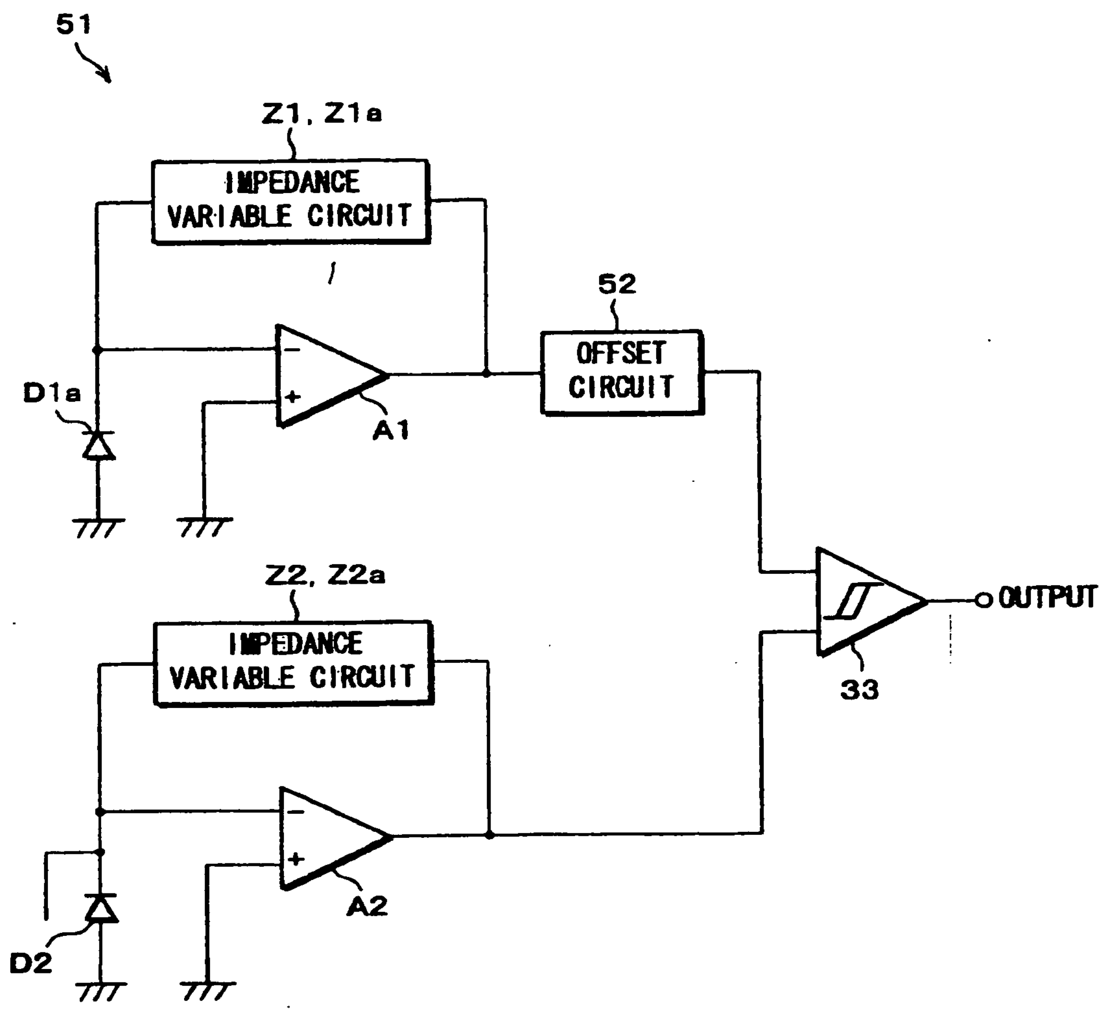

51
Z1, Z1a
IMPEDANCE VARIABLE CIRCUIT
52
OFFSET CIRCUIT
D1a
A1
Z2, Z2a
IMPEDANCE VARIABLE CIRCUIT
OUTPUT
33
A2
D2

FIG. 5

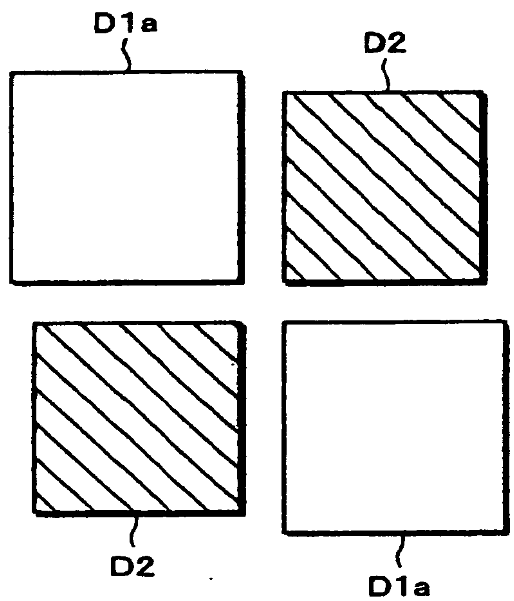


FIG. 6

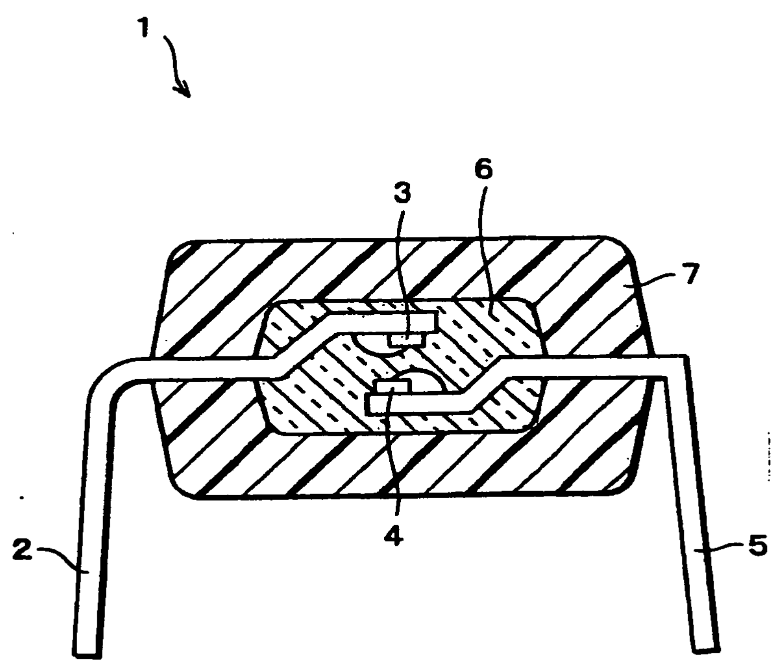


FIG. 7

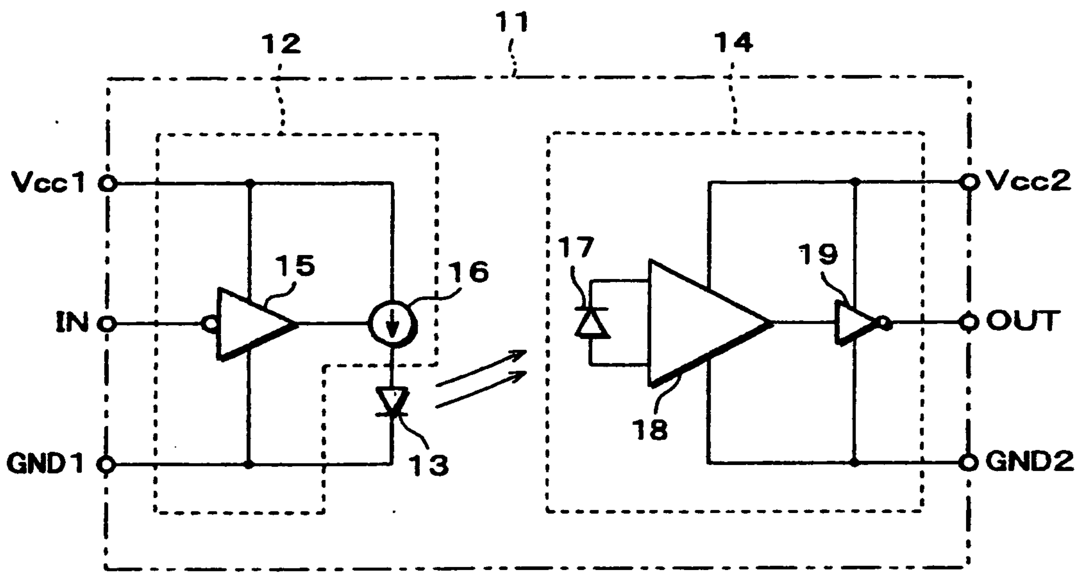


FIG. 8

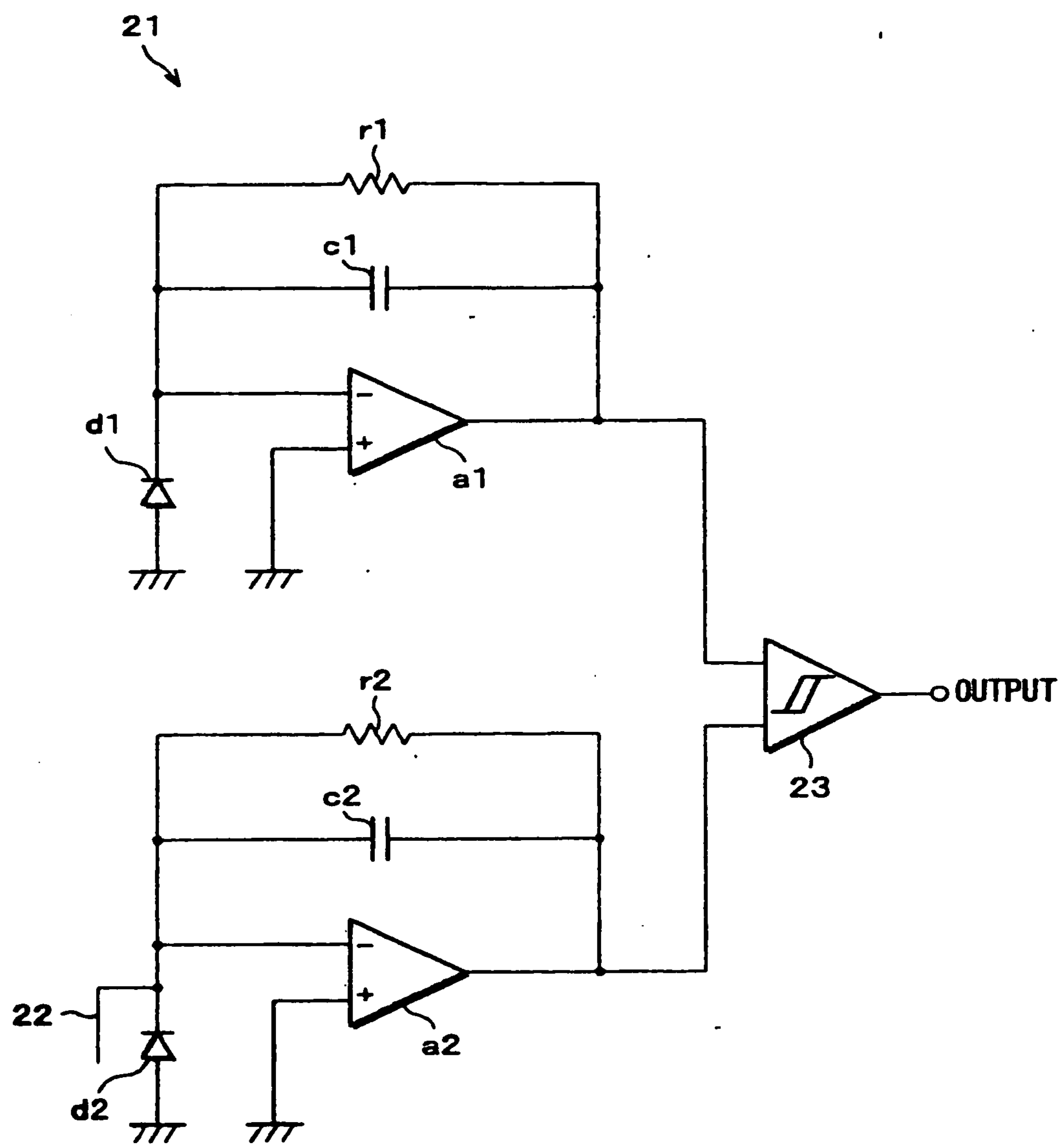


FIG. 9

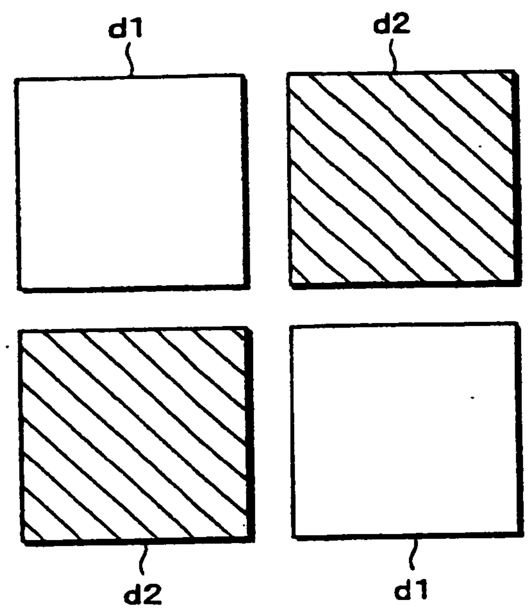


FIG. 10 (a)

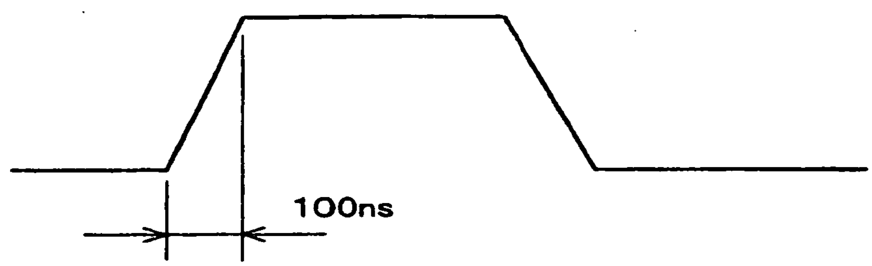
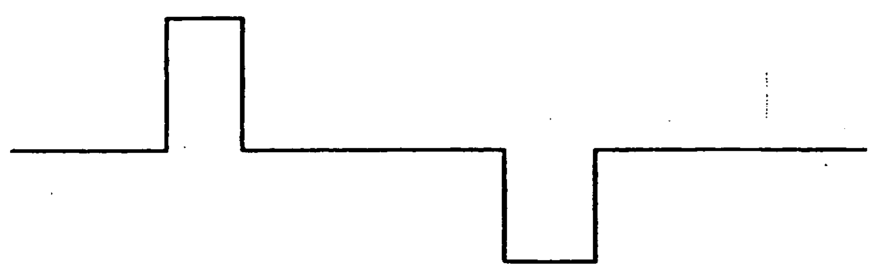


FIG. 10 (b)



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